“We Made Liquid!”: How Children Blend Feedback in a Mixed-Reality Environment for Collective Embodied Learning

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Abstract: With the rapid development of emerging technologies in education, this research, explored how children use teacher-, peer-, and technology-provided feedback together towards collective and embodied learning in a mixed-reality environment. We applied interaction analysis to analyze data from two research sites. At Site A, we focused on how children transitioned from individualized views of feedback to more collective by blending multiple sources of feedback to make sense of states of matter and solid bonds. At Site B, we found that the children took up feedback from their peers, facilitators, and technology to explore how the particles must behave collectively to form liquid. We hope our work informs future designs of learning environments with complex feedback structures to support student inquiry and their agency in blending the feedback sources that best support their collective sense-making process.

Introduction

As educational technology gains popularity in both formal and informal settings, the term “feedback” has referred to different aspects of the defined in the learning environments. Feedback from teachers, usually in the form of scaffolding or formative assessments, have been shown to provide children with opportunities to engage in rigorous, evidence-based, scientific thinking (Kang et al., 2014). The authors argued that these types of feedback were related to an increase in quality of student explanations. However, we wonder how feasible it is to sustain this individualized feedback in formal classrooms, especially given high student to teacher ratio in the U.S. (about 19:1; Public School Review, 2021).

Feedback in learning has previous been studied from objectivist and constructivist perspectives (Mory, 1992; 2004). Although the definition has changed overtime, in this paper, we build off the conceptualization of “feedback” as “information presented that allows comparison between an actual outcome and a desired outcome” (Mory, 2004). We appreciate the broadness of this definition, which allows us to consider multiple sources and pairing of feedback, rather than just the teacher-student or student-student structures often seen in classrooms. Feedback has also been understood in traditional education as input, but in technology research has been viewed as a process that affects a system and its output (Dawson et al., 2018). In this paper, we hope to further the definitions of feedback by considering a mixed-reality learning environment that provides a broader range of feedback sources, namely the self, the teacher, peers, and computers. This novel feedback structure makes it so “both children and teachers have the role of monitoring and responding to effects” (Boud & Molloy, 2013), supporting student agency and a more collectivistic rather than individualistic approach to science.

After reviewing the literature on feedback in classrooms and in educational technology, we will argue two points in the rest of this paper: (1) we think it is important to further study collective technology-enhanced experiences to complement the current focus in the field on the individual or personalized learning; and (2) it is important not only to study what the technology does for children but the diverse resources that children draw on. In other words, this paper aims to reframe emerging technologies and feedback as tools that children have agency over rather than some optimal learning experience children passively undergo. Our research question is: how do children use teacher-, peer-, and technology-provided feedback toward collective scientific sense-making?

Theoretical Framework

Given this motivation to study the *collective* and *agency-enhancing* aspects of children using technology to learn, we draw on two theoretical frameworks to further explore these nuances. First, the Learning through Embodied

Activity (LEAF; Danish et al., 2020) framework pushes us to view technology and feedback through the lens of the *community* rather than an individual student. Second, the liminal blends framework (Keifert et al., 2015, Danish et al., 2020) help us to reframe children's interactions with the feedback from technology, teacher, and peers as resources that they blend in ways that make the most sense for their inquiry. We provide further details about these two frameworks below.

LEAF

In our paper, we consider embodiment as both am individual and collective experience in mixed-reality learning environments. Thus, we built our analysis on the Learning through embodied activity framework (LEAF; Danish et al., 2020), due to the collective experience that this research project's activities were designed to support. In our study, children were exploring the mechanisms of particles in different states of matter, which required at least two children to be a certain distance and moving at certain speed relatively to each other in order for the system to show that they formed a solid, liquid, or gas bond (see Design and Method section for more detail). Building off activity theory (Wertsh, 1986), this design feature children to co-investigate the rules of technology (and therefore science) system. They also co-create their own ideas and strategies about the system, and leverage the feedback from teacher (e.g., asking children to notice and wonder about certain features of the system) to ultimately gain a better understanding of why and how bonds and molecules act in different states of matter.

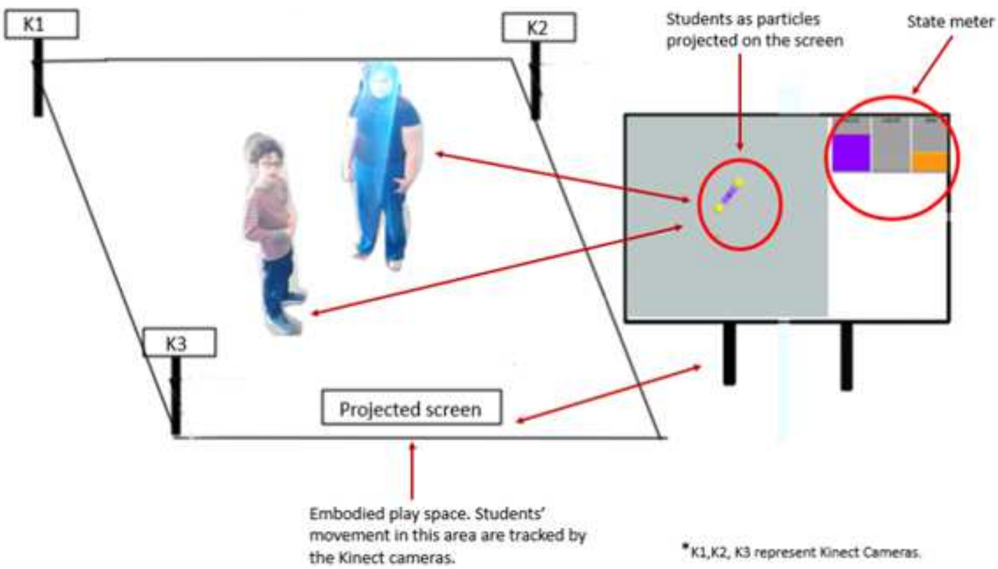
Liminal Blends

We further explore how children leverage different resources in mixed-reality (MR) environments to help them understand the target concepts. Thus, we built our analysis on the liminal blends' framework (Keifert et al., 2015; Danish et al.; 2020). The liminal blends framework builds on conceptual building theory (Fauconnier & Turner, 1998) and extends it to focus on the importance of material resources and the process of blending available resources. Liminal blends also provided a nuanced explanation for how learners can be supported in connecting their individual and collective perspectives within the LEAF framework. While this study was designed to support young children's embodied learning, we saw multiple resources (beyond physical and the body) in the mixed-reality environment. On the technology side, children get real-time feedback in from technological simulations. At the same time, children also work together to get feedback from their teachers and peers. Thus, children constantly respond to the feedback to form their conceptual understanding, and these are not bi-directional. Thus, in our study we aim to explore how diverse types of feedback in a MR environment and facilitators (teacher, researcher) support young children to leverage multiple resources to form a conceptual understanding of the target content knowledge.

Design

The data for this study comes from the larger Science Through Technology Enhanced Play (STEP) project. The STEP environment is a mixed-reality environment, where children's movement was tracked by Microsoft Kinect cameras then transformed to a particle avatar in a computer simulation that projects on a shared screen in front of the classroom (see Figure 1). When children engage in the STEP environment, they see themselves as individual particles on the shared screen but based on their relative movement to others they create solid, liquid, and gas. There are two types of real-time feedback built into the STEP environment: 1) bonds between particles, and 2) state meter which is a bar graph indicating which states children are in.

Figure 1.
Children interacting with STEP environment. Their movement was tracked by the Kinect camera (K1, K2, K3), and then transferred into movement of avatars on the shared screen in front of the children (right). The bonds between children's particles indicate their states.



Therefore, in the STEP environment children are leveraging resources: 1) their embodied movement, 2) feedback from peers and teachers and 3) digital representation in the STEP environment. In this study, we will focus on how real-time feedback from the simulation, peers, and teachers supports children exploring the science content.

Method

Participants and Data source:

This data was collected in the STEP environment across two sites. At Site A, we focused on 13 first and second graders in a Spanish-English bilingual classroom at a progressive elementary located in the Western United States. At Site B, 22 children from a first and second mixed grade classroom in a Midwest city participated in a 7-day curriculum. We chose to include both sites in our analysis to represent the range of science activity facilitating styles (e.g., Site A's site teacher was more hands-on about asking questions to the guide the inquiry, while Site B's teacher preferred giving step-by-step directions). In the focal activities from our data, children were divided into an embodied group and observer group. The children in the embodied group moved around in the tracking area and projected as particles in the simulation. And the observer group watched the embodied group and also provided suggestions for them to adjust their collective movement. The activities at Site A were led by the teachers (this was their second year facilitating this curriculum), while the researchers provided any technical supports. In Site B, the activities were led by researchers, and the classroom teachers sometimes asked prompt questions but did not lead the entire activities.

Even though we collected data from different sites, the goal was not to compare the differences of facilitation, instead, we investigated how different ways of facilitation complement young children's exploration of the target content knowledge. Each site began the data analysis process by writing content logs (Derry et al., 2010) of children progressing through the curriculum. From these content logs, we went back and engaged in iterative viewings of moments that showcased feedback from teachers, peers, and technology (e.g., teacher noticing children's movements, peers shouting when something happens on screen, technology showing a bond when children's particle avatars are a certain distance apart). We then refined our hypotheses about how peer-technology-student feedback work together to help children make sense of states of matter, and chose two focal clips (one from each site) to engage in Interaction Analysis (Jordan and Henderson, 1995). As a research team, we watched the clips once for first impressions, then watched the clips one to two more times, stopping at any moment to make claims related to our guiding research question (How do children use teacher-, peer-, and technology-provided feedback toward collective scientific sense-making?) and grounding our claims in evidence from the video record.

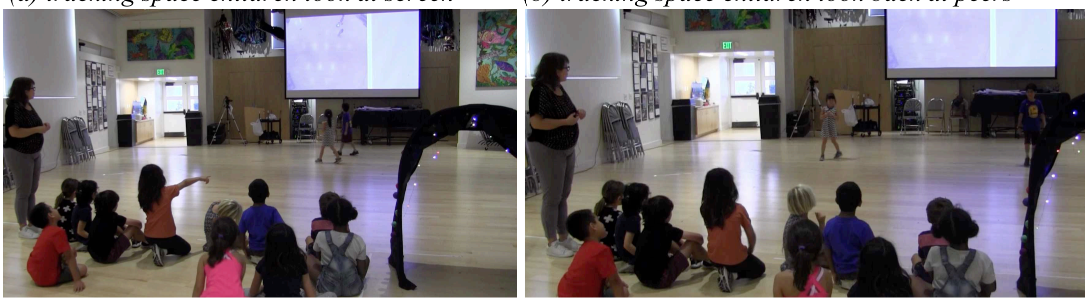
Findings

A consistent finding across both sites was that the feedback structure of the STEP activities were met with positive engagement from the children (e.g., wanting to keep playing until time ran out). We also saw subtle differences that we believe can inform future designs of classroom and digital learning environment activities. In Site A, children expertly synthesized peer, teacher, and the technological system's feedback to make sense of the scientific phenomenon they were trying to model (in this case states of matter). In Site B, children relied more on peers and the technology system's feedback in order to collectively embody the phenomenon being modeled. These two cases may also have implications for how educators with different teaching styles (e.g., more and less hands-on) could facilitate such activities with feedback from emerging technologies like the mixed reality in STEP.

Site A: Children blend individualized and collective feedback from digital representations with support of teacher and peers

In Classroom 1, we focused on Day 2 of the 8-day curriculum about states of matter, when children experienced walking into the embodied tracking space for the first time. The children tried to figure out which particle on screen was linked to their own body movements, and they noticed different things would happen on screen when they run, walk, or stand at different distances from each other. At first, the teacher asked only two children to enter the embodied space as she narrated what happens: *"So explore a little bit. What happens if you walk slower? Walk faster?"* (See Figure 2a). We saw little peer-to-peer interactions at the beginning of this clip despite there being multiple children in the space, perhaps because they understood the teacher's "you" as an individual rather than a collective reference. While the children inside the space have their gaze fixed on the screen, the observer group at the back of the room saw both the screen and their two classmates engaging in the space. The observer group still showed many behaviors that suggested engagement with the technology (e.g., squeals and exclamations of delight in response to the screen). This feedback structure resembled "personalized learning" in that different children receive different feedback (i.e., embodied group listened to the teacher, moved their own bodies, and saw their particle move on screen; observer group saw their classmates' movement map onto the movement of the particles on screen). This environment is still somewhat unique in that children are making sense of multiple resources (social, digital, and physical) simultaneously in order to understand the science activity.

Figure 2
(a) tracking space children look at screen *(b) tracking space children look back at peers*



As the two children continued exploring the space, we started to see feedback structures overlap more between the observer group and the embodied group. The teacher said, *"Okay let them walk around. Let's see what happens"* and both of the tracking space children turn away from the screen (See Figure 2b). Now that they could not see the technological feedback, they could only depend on feedback from peers and the teacher at the back of the room. In this moment, the children recognized that the technology's feedback was not solely for themselves, but for the whole class, and therefore they could rely on their classmates to help make sense of the system. This transition from looking at the screen to the back of the room showed children' abilities to blend the feedback sources they are receiving, foregrounding some more than others, in this case when they found peer feedback more helpful than the individualized feedback.

Even when more friends were added to the tracking space, children' abilities to blend multiple sources of feedback did not falter: In fact, children began to make connections between how they collectively used their bodies to how particles in different states of matter move. After the teacher asked if more children should go into the space, many children raised their arms immediately and enthusiastically. The teacher chose four more children to enter, and the technology began to show "bonds," represented by different colored and patterned lines connected between the particle avatars. The teacher noticed that one girl's particle color changed on screen when she was in close proximity with another girl and her particle (now representing a "solid" bond). Other children started to pair up and attempted to recreate the same phenomenon. The teacher did not give away the distance-based rule she already knew about the system, but instead the children explored leveraging the teacher's prompting, their peers' feedback, and their own individual feedback received from the technology/the screen. This episode showed us how children went from first relying mostly on individualized feedback from the technology, to eliciting feedback and support from observing peers, to adeptly blending multiple sources (teacher, peer, and technology) to make sense of particle bonds.

Site B: Children make sense of peer feedback and multiple digital representations

Our second example focused on the day that children were exploring particles' behavior in different states. This is the first day children started to try collectively embodying particles in certain states. In this activity, the way teachers and researchers gave feedback and the simulation feedback to the children was slightly different from the above clip. First, the observer group noticed two important characteristics of particles in the STEP simulation: bond (line between particles) and speed. Second, the researchers gave both individual feedback to children who came to them to raise their ideas, and to the entire classroom to communicate between the embodied group and the observers group. Last, for STEP environment, the "State meter" gave children real-time feedback about what states they are in (bar chart, Figure 1, right), prompting children to recognize the states they are in and therefore adjust their movement in the space.

The goal of this activity was to help children explore how particles move in different states of matter, as they embody particles for the first time. We focus on a clip of a group of children exploring how *liquid particles* move in a tank. They leveraged the feedback from both their peer, teachers, and the simulation to collectively embody particles in liquid. After several short rounds of free exploration in class, several children already engaged with the STEP environment without much prompting. Then the researcher invited a group of four into the space to act as particles. The researcher started with asking the small group "What are we going to make right now" (Figure 3, line 1), and several children answered with "liquid". The researcher asked children "What do you think you need to do to make liquid?" Here the researcher was trying to help children think about how to move in the space as a liquid particle.

As one student, Lily (all names are pseudonyms) first looked at the shared screen, she tried to find herself on the shared screen. At this moment, each child was moving at their own pace. Even though Lily tried to find herself in the STEP simulation, she couldn't form liquid by herself. Then an observer, Jane, came into the space, and talked to the researcher *"I think they need to be far apart and the line is longer*". At this time, Jane was the first child who noticed the line between particles. She came to the researcher and used a gesture to show the group needed to be further apart to make ta longer line. The line between particles was designed in three different colors and length to represent attraction and distance (green as liquid, blue as solid, etc.) The line was shown based on children's tracked movement; for example, if children are really close and move slowly, the line would be projected as blue. Then the researcher first confirmed with Jane about her ideas and tried to introduce this idea to the embodied team to adjust their distance.

Figure 3.

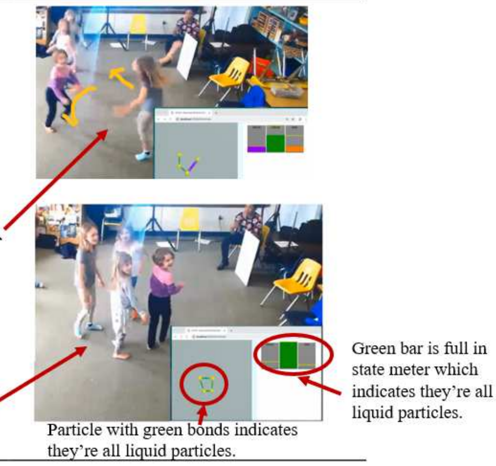
Lily and Jane explore how to form a liquid bond

Turn	Verbal	Non-verbal
1 Researcher	What's the goal, what I'm hearing?	
2 Researcher	Liquid	
3 Lily	Oh, there we go (looking at the screen)	
4 Researcher	Liquid?	
5 Lily	I want that one	
6 Jane	I think they need to be far apart. And the line is longer (She used a gesture to show they need to be further apart)	
7 Researcher	Oh, so when they are far apart. What's longer	
8 Researcher	Can everyone hear Jane (an observer) said?	
9 Researcher	So she said if you're further a part, it makes a line. particles. longer?	

However, the embodied group didn't pay attention to Jane, as they were still trying to look at the shared screen and tried to step back and stay away from the other children to represent the liquid particles. Then Lily also realized they needed to adjust the distance, but since other children were still moving around, she could not form liquid by herself. In STEP, children need to collectively embody the particles and their relative distance and speed to represent a certain state. Then she showed the researcher a gesture that pulled her hands apart to represent distance between the particles (See Figure 4). Thus, the researcher encouraged her to show her gesture to the group. After Lily got feedback from the researcher, she went back to the embodied tracking space and used the same gesture to show her peers (See Figure 4). She told her peers to "stay away back" so that they could be recognized by the simulation as liquid particles. With Lily's suggestion, the embodied team adjusted their distance, but they were not recognized by the projection as liquid particles

As Lily's team continually adjust their distance and try to figure out how to be recognized by the simulation as liquid particles. Another boy, Paul, talked to the researcher "they need to move." Even as an observer, Paul realized the speed matters to make liquid particles. Then the embodied group started to wander around again, but they couldn't form liquid particles since they are all moving at different speeds. Then Lily suggested her team work together again: "Why don't we move and keep the same amount of space?" Here, children started to work collectively to adjust their distance and speed, and finally they successfully formed liquid particles. They recognized they succeeded based on the state meter on the shared screen (Figure 4).

Figure 4.
Paul suggests team to move around

Turn		Verbal	Non-verbal
1	Researcher	Paul said something, what did you say?	
2	Paul	They need to move	
3	Researcher	Paul said you need to move. Oh, we see some changes.	
4	Lily	Why don't we move and keep the same amount of space?	
5	Embodied group	(Walking in the space while maintaining the distance between each other)	
6	Lily	We made liquid!	

In this case, children started to move at their own pace in the tracking area, but due to the design of the simulation, multiple particles are needed to form certain states. Thus, the embodied group leveraged the resources from the simulation, the feedback from the observer group, and their teacher to achieve this complex goal. The simulation offered real-time feedback on the states of children's particle with: 1) the line between particles and 2) state meter bar. The observers in these clips provided two useful suggestions: 1) the embodied group needed to adjust their distance to make the "line" longer, and 2) they needed to move. These suggestions helped children to explore key characteristics of particles built in the STEP environment: distance and speed. We also found other clips of how the teacher's feedback and the feedback from technology support children collaboratively exploring how particles move. In future studies, we hope to present more and varied examples of how children use multiple sources of feedback towards this kind of collective embodied learning.

Discussion and Implications

In this paper, we explored how embodiment helped support young children to represent ideas in complex systems. In Site A, we showed how children went from relying on individualized feedback to more collective feedback, and leveraged many different types of resources (social, digital, and physical) in their inquiry process throughout this activity. Both these findings align with the LEAF and liminal blends frameworks and show that children are capable of collaborating to make sense of multiple and complex feedback structures (e.g., teacher, technology, and/or peer). We argue that the resulting engagement is greater than the sum of engagement resulted from any of the "parts" of these feedback structures (e.g., the teacher alone or only technology-provided feedback). By combining the feedback they receive, children discovered novel uses for these different resources: For example, the children in Site A quickly discovered that the technology does not only give feedback on individuals but can also give feedback on a classmate's position in relation to oneself. In future iterations of this project, we hope to incorporate student input and co-design methodology to open up possibilities of the different ways children may use the technology that research may not be able to predict.

In Site B, we saw children lead their own inquiry and expertly navigate coordinating multiple bodies in order to receive a desired feedback from the technology. Although the researcher supported student noticing with question prompts, children were quick to understand that certain representations (i.e., the state meter) appeared if they worked together to position themselves in certain ways and move at certain speeds. We hope that future educational technology researchers and designers can continue to think of ways to support this kind of collective learning and children's agency in blending multiple sources of feedback.

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